Science Highlights
from the National Synchrotron Light Source

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X20C

PUBLICATION
H. Kim, C. Detavenier, O.van der Straten, S.M. Rossnagel, A.J. Kellock, and D.-G. Park, "Robust TaNx diffusion Barrier for Cu Interconnect Technology with Sub-nanometer Thickness by Metal Organic Plasma-Enhanced Atomic Layer Deposition," *J. Appl. Phys.* **98**, 14308 (2005).

FUNDING
IBM Research
U.S. Department of Energy

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Thin Films With Potential Electronics Applications

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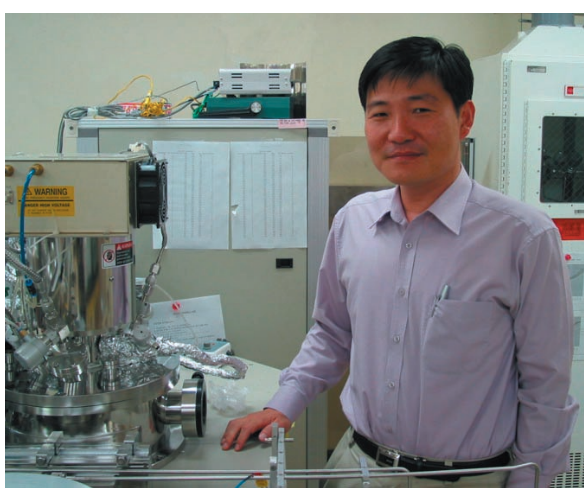
TaN_x diffusion barriers with good barrier properties at sub-nanometer thickness were deposited by plasma-enhanced atomic layer deposition (PE-ALD) from pentakis(dimethylamino)Ta. A hydrogen and/or nitrogen plasma was used as the reactant, producing TaN_x thin films with different nitrogen content. The film properties, including the carbon and oxygen impurity content, were affected by the nitrogen flow during this process. The film, deposited using the hydrogen-only plasma, forms nanocrystalline grains while an amorphous structure was obtained by using the nitrogen plasma. The diffusion-barrier properties of deposited TaN films, as for Cu interconnects, have been studied using thermal stress tests based upon synchrotron x-ray diffraction. The results indicate that the PE-ALD TaN films are good diffusion barriers even at thicknesses as small as 0.6 nm. Better diffusion barrier properties were obtained for films with higher nitrogen content. Based on a diffusion kinetics analysis, the nanocrystalline microstructure of the films was responsible for the better diffusion barrier properties compared to polycrystalline PE-ALD TaN films deposited from $TaCl_5$.

Among the key materials used for today's semiconductor processing, thin films of inert, refractory materials are expected to be used continuously in Cu interconnect applications, such as diffusion barriers and seed and adhesion layers, as well as for potential front-end applications, such as contacts or gate metallization. With the scaling down of these devices, atomic layer deposition (ALD) has been spotlighted due to its ability to produce highly conformal films. The use of a metal organic (MO) precursor for diffusion-barrier ALD has the benefit of producing a chlorine-free diffusion barrier. However, the diffusion-barrier properties of MO-based ALD TaN layers for Cu interconnects were not studied systematically.

In this study, we have developed a metal organic PE-ALD method for depositing TaN thin films from pentakis(dim ethylamino)Ta (PDMAT) using nitrogen and hydrogen plasmas as the reactants. A solid PDMAT (powder) source contained in a glass tube was used as a metal precursor. Atomic hydrogen and activated N_2 were generated by a quartz tube connected to the sample chamber via a gate valve, and hydrogen and nitrogen gases were supplied via a leak valve. For Cu diffusion-barrier measurements, a 200 nm Cu layer (created via physical vapor deposition (PVD)) was deposited on top of the PE-ALD TaN layer, without breaking the vacuum, using a UHV (ultra high vacuum) sputtering system with a power level of 1 kW (dc). A SiO_2 buffer layer placed between the poly-Si layer and Si (100) substrate was used on the other samples to electrically isolate the Si(100) substrate during the sheet-resistance analysis.


Professor Hyungjun Kim

Copper diffusion-barrier failure was studied using three different in situ techniques, including synchrotron x-ray diffraction (XRD), optical scattering, and sheet resistance measurements, conducted simultaneously, while the samples were annealed at a temperature ramp rate of 3 °C/s from 100 to 1000 °C in a He environment. The analysis was completed at National Synchrotron Light Source beamline X20C.

Figure 1 shows the synchrotron XRD contour map for MO PE-ALD TaN films of three different thicknesses -- 3 nm, 0.6 nm, and 0.3 nm -- that were all grown with hydrogen plasma. For the 3 nm thick film, the Cu 111 peak begins to disappear at about 750 °C, indicating the good diffusion-barrier property of the MO PE-ALD TaN film. Even after decreasing the thickness to 0.6 nm, the Cu 111 peak begins to disappear at temperatures higher than 700 °C. Thus, the thermal diffusion-barrier properties of MO PE-ALD TaN films are excellent even at sub-nanometer thicknesses. Only for film thicknesses smaller than 0.3 nm, where the film is only a couple of monolayers thick, does the Cu silicide formation occur at a temperature below 500 °C. Even for this ultra-thin film, however, most of the Cu layer stays intact, judging from the observation that the Cu 111 peak intensity remains high up to 720 °C. Thus, we can conclude that the formation of silicide occurs locally (where the TaN film is not formed evenly). The barrier-failure temperatures for MO PE-ALD TaN layers, obtained from Figure 1, are represented in **Figure 2**. The barrier-failure temperatures increase with increasing thickness. For comparison, the previously reported barrier-failure temperatures for PE-ALD TaN films from $TaCl_5$ and a hydrogen and nitrogen mixture with stoichiometric composition, which were analyzed using exactly the same conditions, are also shown. From the microstructure analysis, done via XRD and transmission electron microscopy (TEM), the good diffusion barrier property of MO PE-ALD TaN is due to the amorphous microstructure of the film. In this sense, PE-ALD films with engineered microstructures and compositions are very promising barriers in the near-future integration of Cu interconnect technology.

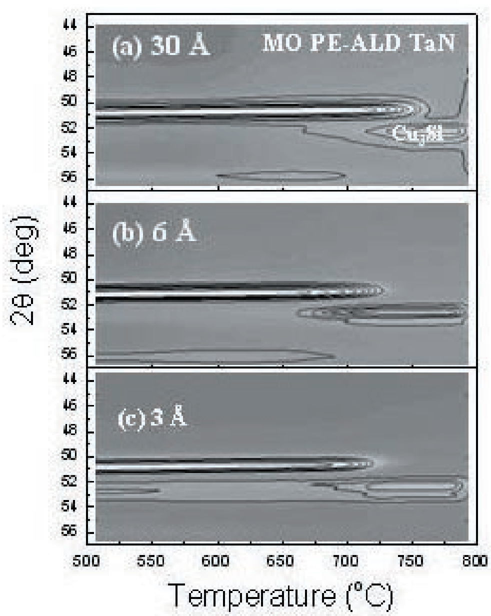


Figure 1. *Synchrotron x-ray diffraction analysis as a function of annealing temperature for a 200 nm PVD Cu/ MO PE-ALD TaN/poly-Si test structure with TaN thicknesses of (a) 3 nm, (b) 0.6 nm, and (c) 0.3 nm. The samples were annealed at 3 °C/s from 100 to 1000 °C in forming gas.*

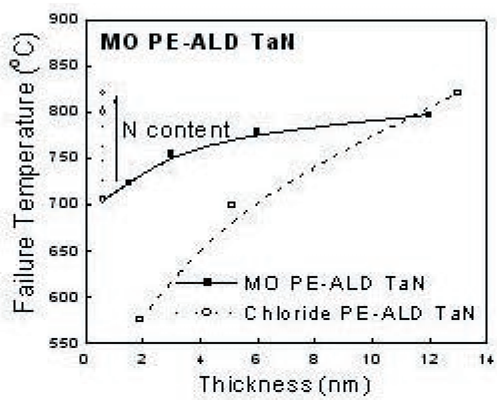


Figure 2. *Barrier-failure temperatures determined using synchrotron x-ray diffraction analysis for MO PE-ALD TaN (black squares) and chloride PE-ALD Ta (open circles). Also shown are the failure temperatures of 0.5 nm MO PE-ALD TaN_x deposited at different nitrogen plasma conditions (open squares).*